Using New Technologies to Improve the Prevention and Management of Chronic Conditions in Populations

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Annu. Rev. Public Health 2015. 36:483–505

First published online as a Review in Advance on January 12, 2015

The *Annual Review of Public Health* is online at publhealth.annualreviews.org

This article's doi: 10.1146/annurev-publhealth-031914-122848

Keywords

health, behavior, technology, intervention, chronic disease, prevention, self-management, noncommunicable disease

Abstract

Lifestyle factors are important in the development of chronic diseases, such as heart disease, respiratory disease, and diabetes, and chronic disease risk can be reduced by changes in lifestyle behaviors linked to these conditions. The use of mass media and community-wide strategies targeting these behaviors has been extensively evaluated since the 1970s. This review summarizes some examples of interventions and their use of media conducted within the old communications landscape of the 1970s and 1980s and the key lessons learned from their design, implementation, and evaluation. We then consider the potential and evidence base for using contemporary technology applications and platforms—within the new communications landscape—to improve the prevention and management of lifestyle-related chronic diseases in the future. We discuss the implications and adaptation of lessons derived from the ways in which new technologies are being used in commercial and political contexts and their relevance for public health. Finally, we consider some recent examples of applying new technologies to public health issues and consider some of the challenges in this rapidly developing field.

COMMUNITY INTERVENTIONS CONDUCTED WITHIN THE OLD COMMUNICATIONS LANDSCAPE

Seminal epidemiological studies of the 1950s and 1960s (33, 38) demonstrated the influence of lifestyle-related factors in the development of chronic diseases, such as cancers and heart and respiratory diseases. The potential to ameliorate the risk and burden of lifestyle-related chronic disease using lifestyle-based behavior change strategies was soon realized and continues to this day (47). In developed countries, theory-based community interventions targeting lifestyle-related behavior risk factors commenced in the 1970s and have continued to the present day.

Community Studies in the 1970s

The North Karelia Project, Finland. In the early 1970s, Finland had one of the highest cardiovascular disease (CVD) mortality rates in the world. The North Karelia Project started in 1972 as a national pilot and demonstration program aimed at reducing population levels of well-established CVD risk factors and thus the incidence of CVD (73, 103). This comprehensive, community-wide intervention program utilized multiple lifestyle change strategies, including use of the state-of-the-art mass media of that time—that is, radio, television, billboards, newspapers, magazine articles, pamphlets, and other printed materials—combined with environmental and legislative approaches. The project developed and evaluated a model that systematically addressed the steps leading to changes in social norms and community-wide behavior change. After the initial intervention phase (1972–1977), the project findings and lessons were further adapted and more widely implemented to develop a comprehensive national heart health program in Finland. An evaluation involving population surveys and disease registers showed that the population risk factor levels in Finland were greatly reduced over the ensuing 30 years and that the age-adjusted CVD mortality rate among the 30–64-year-old male population was reduced from 73% to 65% between 1970 and 1995 in North Karelia and all of Finland.

The Stanford Community Studies, United States. The Three-City Stanford Community Study aimed to reduce cardiovascular risk factors, including dietary fat intake, in two towns in California, with a combined total population of 30,000 for this study, using messages delivered via mass media and other strategies (120). After two years of intensive intervention, a reduction in the average dietary fat content of 25 grams per day was demonstrated in both intervention areas, compared with three grams per day in the reference area. Results suggested that educational campaigns delivered to communities using mass media could reduce the risk of CVD. Other community-based CVD risk reduction trials that commenced in the early 1980s, such as the Stanford Five-City Study and the Minnesota Heart Health Program, further developed and applied similar intervention strategies using the state-of-the-art mass media of the time, such as public service announcements on television and radio. The mass media and other strategies designed, implemented, and evaluated for these large community-based project studies were then subsequently adapted and evaluated in many other communities around the world (102), including low- and middle-income countries (LMICs) in Asia, Africa, and Latin America in more recent years (16, 40, 75, 98).

Lessons Learned

Over time, the mass media and other strategies used in the community trials of the 1970s and 1980s were also combined with policies and legislation to shift social norms and to make at least some

healthier lifestyle choices—such as quitting smoking—easier. However, by using the evaluation study designs and measurement approaches that were available at that time, it was often difficult to disentangle the effects of these interventions from secular trends. The broader community was also being impacted by the increasing awareness of the lifestyle message, which was being spread by the wider use of mass media and the implementation of regulations and policies (117). This sea change prompted the need for more refined and carefully evaluated interventions addressing smaller, better-defined populations in workplaces and other community settings, using cluster randomized and other study designs, with more emphasis given to process evaluation (117, 134).

Contemporary Challenges for Prevention and Control of Lifestyle-Related Chronic Conditions

In recent years, lifestyle-related chronic conditions, such as CVD, diabetes, their comorbidities, including common psychological conditions, and the key lifestyle behaviors causally linked to these, have become the most important contributors to the global disease burden (47, 128). This article considers the ways in which lifestyle-related chronic conditions can be addressed within the new communications landscape, characterized by information and communication technologies (ICTs) that utilize the Internet, mobile technologies [mobile health (mHealth)], social media, and, most recently, many different kinds of "smart" wearable devices to measure key health behaviors, e.g., physical activity in relation to an individual's geographic position. When such technologies are used to deliver well-designed, consolidated, and program innovations, they can (*a*) reach large numbers of individuals and populations at relatively low cost; (*b*) reduce the amount of direct human contact required for program delivery; (*c*) address multiple key functions of effective health behavior change programs simultaneously, including the provision of education, coaching, monitoring, and social support, with high fidelity (46); and (*d*) generate large amounts of data that can be used in real time to inform and guide dynamic, adaptive, more effective, and sustainable programs. However, to date, the potential of these new technologies is not being fully realized in terms of their impact on public health and other key outcomes (25). Three key interrelated reasons for this are (*a*) poor program design and implementation of many of the program innovations using new technologies; (*b*) poor user interface with these programs and/or a lack of perceived benefit from users, including poor integration with users' daily routines (67); and (*c*) inadequate study design and measurement methods for evaluating the implementation of technology innovations in real time, resulting in the inability to adapt and to make rapid improvements. Furthermore, the population with the highest burden of chronic diseases consists of older adults, many of whom still demonstrate a preference for more traditionally delivered programs; however, this is also changing rapidly (51, 67). In the following section, we describe and review some of the new technology platforms for different health applications as well as current evidence regarding their reach, effectiveness, adoption, implementation, and maintenance (9).

WHAT WORKS, WITH WHOM, AND UNDER WHAT CONDITIONS?

The recent, rapid advances in interactive digital technologies have significantly changed the ways in which communication and social interaction are occurring globally. The Internet, Facebook, Twitter, Wiki, and technology platforms using smart phones and mobile computers (tablets) have created unprecedented opportunities to reach, engage, and interact with individuals globally and beyond traditionally defined communities (115). The rapid uptake of social media is demonstrated by the number of Facebook users at the end of its first year in existence in 2004 (1 million); it now has approximately 1.23 billion monthly active users, 945 million of whom use mobile devices (43). In

China, which boasts the world's biggest Internet user base of more than half a billion people, there are already an estimated regular 220 million bloggers. Furthermore, Sina Weibo, China's largest Web portal, already has more than 50 million active users per day and an estimated 10 million newly registered users per month (24). Furthermore, contemporary digital communications now go way beyond the use of simple words and text and also include photos, videos, three-dimensional images, visual simulations, and even virtual reality; and all of these are being incorporated into various devices and platforms. Underpinning these changes in the communications landscape is the shift from Web 1.0, which involved Internet sites simply providing information in a library format, to Web 2.0, which refers to the new era of Web-enabled applications for user-generated and user-manipulated contents, such as blogs, podcasts, and social networking sites, providing a platform for much more immersive and social user experiences. More recently developed mHealth platforms using smart phones and computer tablets can utilize the Web 2.0 platform for the delivery of health behavior change programs and tools to improve health and the management of lifestyle-related chronic conditions.

The prospect of effective technology innovations with high reach, high fidelity, and a very good user experience suggests that ICT has great potential to improve the health of populations around the world—particularly in LMICs (98)—and way beyond those delivery channels and technology platforms that were used for public health interventions and programs in 1970s and 1980s. For example, social media apps, such as Facebook, WhatsApp, or Instagram, are being used to disseminate health information and support by replicating real world relationships and networks to support like-minded people with similar interests. An additional five contemporary examples of ICT programs and applications being used for health applications, include the use of the following:

1. User-generated data sharing platforms, such as PatientsLikeMe (**http://www.patientslikeme.com/**), provide patients with a health information sharing platform by which they can learn from and connect with others like themselves, and track their health.
2. Adaptive learning and personalized recommendation engines, such as Ginger.io (**https://ginger.io/**), provide two services. This three-part platform (patient app, behavioral analytics engine, and provider dashboard) tracks users' behavioral health information (location, calling/texting records, sleep patterns, app usage) while the behavioral analytics engine concurrently identifies trends in behaviors that may indicate underlying health issues, such as behaviors associated with depression, e.g., decreased communication and/or reduced movement.
3. Coaching and telehealth provide for more options in health care, such as Breakthrough (**https://www.breakthrough.com/**), an online platform that connects licensed therapists to therapy seekers who are too busy for typical 9 AM to 5 PM sessions. Breakthrough has also developed partnerships with insurers to make this a viable option with no out-of-pocket expenses, thus attempting to remove the typical barriers of location, time, and expense.
4. Social support is provided online to motivate and sustain healthy behaviors. One example is Helpmedoit! (**http://controlled-trials.com/ISRCTN85615983**), a Web- and text-based intervention that facilitates social support to achieve and maintain health-related changes in physical activity and dietary behavior. Its three key facilitators are goal setting, monitoring by self and others, and social support.
5. Community-sourced monitoring of emerging public health threats is available via websites, such as HealthMap (**http://www.healthmap.org/en/**), and via mobile apps, such as Outbreaks Near Me, which delivers real-time information on emerging infectious diseases

by consolidating disparate data sources, such as news aggregators, eyewitness reports, and validated official reports.

Key Features of Using Contemporary Technology Approaches for Public Health Innovations

Although the potential utility of ICT to improve public health now seems obvious, it is important to consider some of the key distinguishing features between the old and the new communications landscapes and to identify how contemporary delivery of public health programs can incorporate the key elements and components of more traditionally delivered approaches.

Standardizing, tailoring, and promoting user-generated information. Program content and messages delivered by new technologies can demonstrate a high degree of fidelity, standardization, and replicability, thus reducing the likelihood of variable delivery by health professionals. The emergence of computer software and the development of expert systems originally developed in the 1990s have contributed to more sophisticated tailoring of programs (71, 76). This algorithm-driven approach can combine the benefits of more traditional mass reach media with much more individually tailored interventions for a very large number of individuals or populations. Combining this approach with new technologies that can also crowdsource feedback and data from many thousands of participants in real time; allows for the delivery of program content that can be made relevant for multiple circumstances, contexts, and situations; and can at the same time be unique to individual users by considering their preferences for content and mode of program delivery. Although traditionally delivered health education and health promotion programs could obviously be tailored for small numbers of individuals, new technology platforms can be used to deliver highly personalized, standardized, and tailored messages to whole populations. This is why new technologies are so disruptive for the delivery of public health programs because this has never been possible before in human history.

Furthermore, the rapid evolution and uptake of smart phones and handheld computers is leading to increased use of social media for health programs, with interactive capabilities that are significantly challenging our traditional approaches to standardizing programs and their delivery. Individuals can now interact with, shape, and even disseminate their own intervention messages through their social networks by using features, such as comments, likes, shares, and tweets. However, it is critically important that programs delivered via such platforms are designed and delivered with an understanding of the user experience and how individuals will respond to, shape, and share such content and programs (25, 29). For example, a recent study revealed that positive and derisive viewer comments shaped other users' evaluations of the credibility of antimarijuana health messages delivered via YouTube (127). It has also been shown that user engagement of Internet-based behavioral interventions for chronic disease is improved by addressing health concerns that are important to the individual, and this is further enhanced by incorporating personally tailored advice and feedback (68, 113).

Anonymity and privacy. When compared with traditional in-person interviewers or paper-and-pencil surveys, individuals tend to reveal more sensitive and private information about behaviors and their lives via computers (59, 64, 121). For example, in the case of email or online surveys, participants can complete surveys in their own environment and thus experience a sense of security, which can lead to more complete, truthful responses (130). Research also suggests that individuals are more likely to undertake health promotion and other kinds of programs for sensitive or stigmatized issues, such as mental health, sexuality, eating disorders, and/or substance use, by using new technologies (20, 130).

Program engagement and mobility. When delivered by the Internet accessed by a traditional personal computer (PC), or more recently, via smart phones and tablets, ICT interventions can be made graphically rich and absorbing by using highly interactive tools to increase usability and program engagement. This is known as the gamification of health care and involves computer- and Internet-based programs providing individuals with instant feedback and interaction with the program (a key feature of computer games), which elicits absorption and increases user attention and engagement (6). A recent report (32), titled "Gaming to Engage the Healthcare Consumer," suggests that the increasing popularity of gamification in health care is driven by an increase in value-based care, which has prompted a focus on the prevention of diseases like diabetes or CVD, often involving behavior change, an area where games demonstrate the potential to make the programs and intervention more attractive. This attention and engagement is especially relevant for younger, technology-native users who value interaction with components in competitive video games designed around a health message or theme (10, 97). In addition, enhanced autonomy and self-efficacy can both be achieved by providing technology-based programs that allow flexibility in terms of where and when users can access them. As Web-enabled phones and tablets that receive and send data become much more accessible and affordable than computers, they also provide an excellent platform for the rapidly expanding field of mHealth programs and related applications (74, 93). Indeed, most smart phones and tablets are now as powerful as, and have more portability and flexibility than, traditional PCs, and when combined with the increased affordability of Internet access, they are rapidly becoming the device of choice for a large proportion of individuals. However, around the world as online health consumers seek up-to-date information as well as information they can really trust (55), the challenge is how best to convey accessible, accurate, up-to-date, and highly credible information while still capturing the viewer's attention for the program's duration.

Program costs and reach. Two promising features of ICT-delivered public health interventions are the associated costs and potential reach when scaled up (53, 109). Although initial development costs may be relatively high (and variable), the low marginal costs of making programs available to large numbers can result in significantly lower overall costs over time. This is true of programs that require no or minimal human contact, with many ICT health programs now only requiring a moderator, coordinator, or health professional to oversee the program and its use. Although such program delivery may become less expensive as automated interactive systems become more sophisticated, the costs and benefits of such programs still remain undetermined, and the cost of integrating personal contact may be significantly underestimated (83).

Evidence for Effectiveness, Uptake, and Use of Technology Interventions for Public Health

Despite clear potential and a burgeoning literature that advocates the increased use of new technologies to improve public health (13, 58, 92), rigorous evaluation of their use and outcomes is very important and still lacking.

Overview of systematic reviews of technology-based health interventions. To evaluate the effectiveness, uptake, and use of technology-based interventions, we undertook a review of systematic reviews with the following inclusion/exclusion criteria: (*a*) published between 2010 and June 2014, (*b*) included primary studies of ICT to prevent and/or control lifestyle-related chronic diseases, (*c*) involved adult populations, and (*d*) primarily used technology for delivery of the innovation (see **Supplemental Table 1**; follow the **Supplemental Material link** from the Annual Reviews home page at **http://www.annualreviews.org**).

Supplemental Material

A total of 58 systematic reviews containing 1,686 studies (mean = 29/systematic review, range 7–113) were included, with pooled sample sizes ranging from 858 (99) to 69,026 (100); the sample sizes of the individual studies ranged from 6 to >500. The reviews variously targeted lifestyle-related chronic conditions [osteoarthritis, CVD, hypertension, type 2 diabetes, asthma, chronic obstructive pulmonary disease (COPD)], common mental disorders (depression, anxiety), and/or lifestyle-related risk factors (excessive alcohol use, physical inactivity, smoking, poor diet). Less than 5% of all studies included appeared in more than one systematic review, indicating the breadth and diversity of studies reviewed. The major modes of program delivery were (*a*) mHealth, text messaging, mobile, and/or smart-phone technologies (n = 21) (5, 7, 14, 19, 23, 35–37, 39, 41, 44, 52, 62, 80, 90, 94, 98, 104, 110, 114, 119); (*b*) Web- or Internet-based programs (n = 23) (3, 8, 15, 42, 49, 60, 70, 72, 78, 81, 82, 84, 89, 96, 105, 106, 108, 111, 118, 124, 129, 131, 135); (*c*) telehealth and/or telemonitoring (n = 9) (1, 21, 28, 56, 65, 85, 99, 100, 125); and (*d*) social media (n = 3) (22, 87, 123). One review included studies of mobile and Internet-based technologies to promote physical activity for individuals with type 2 diabetes (31).

Mobile or mHealth interventions. Four reviews evaluated mHealth interventions targeting individuals with type 1 and/or 2 diabetes, all of which identified mHealth programs demonstrating a significant pre- to post-reduction in glycosylated hemoglobin (HbA1c) compared to standard care (7, 62, 80, 110). Liang et al. (80) reported that the mode of mobile phone intervention varied among the 22 studies reviewed; 14 used a short messaging service (SMS) and the Internet as support for self-monitoring blood glucose (BG) levels, reinforcement of diet, exercise, and medication adjustment; 8 adopted SMS alone or SMS combined with other technologies such as Bluetooth; and 1 combined mobile phones with clinical visits from a diabetes specialist nurse. Holtz & Lauckner (62) found applications delivered via mobile devices, developed specifically for a study, had more functionalities than regular text messaging, e.g., information and/or education about and diaries/logs of diet, physical activity, and BG control (62). Baron et al. (7) reviewed studies that evaluated interventions in which individuals used mobile devices to transfer data to a Web server and received feedback on HbA1c. Finally, Saffari et al. (110) reviewed six studies that used SMS to send and receive data (interactive approach) relating to BG, diet, physical activity, and medication adherence. Neither an intervention that provided algorithm-based insulin doses using meal content information transmitted via mobile devices nor a nondietary-focused intervention that provided BG results and/or self-management information via SMS was proven effective for type 1 diabetics (7, 80). mHealth technologies for type 2 diabetes (which commonly involved the exchange of information about BG, blood pressure, weight, exercise, diet, medication, and/or well-being to a Web server) were most effective when combined with health care professional feedback. Saffari et al. (110) also showed mHealth interventions using interactive approaches for gathering and providing data reduced HbA1c more than studies with unidirectional (only data collection) approaches, as did those using SMS and the Internet.

Two reviews that focused on mHealth interventions for individuals with mental health disorders (39, 41) had some contradictory findings. The former reported handheld computers were less effective than traditional cognitive behavioral therapy (CBT) for the treatment of anxiety symptoms. The latter reported significant reductions in depression, stress, and substance abuse among users of mental health programs via smart-phone apps. An additional 11 reviews evaluated mHealth interventions that used mobile phones to provide individually tailored, self-monitoring feedback and communication on specific health behaviors, such as weight loss (5, 114, 119), physical activity (14, 44, 94), smoking cessation (41), or a combination of diverse health behaviors, including sunscreen use (19, 36, 52). Results ranged from short- to medium-term evidence of effectiveness for reducing BMI (5), increasing and maintaining physical activity (14), and weight

loss (19). Finally, one systematic review evaluated studies of health care applications for smart phones; almost 80% of these were developed for the iOS platform (90), the mobile operating system developed by Apple Inc., which powers many of the company's iDevices (e.g., iPhone, iPad). The health care applications reviewed were categorized by the user groups targeted (health professionals, medical and/or nursing students, patients) and their main purpose (disease diagnosis, medical calculators for clinical scores, help clinicians provide counseling and support, encourage general health). The widespread adoption of smart phones by the general public highlights a significant opportunity to improve mHealth and mobile telemedicine services through patient-oriented applications. However, the majority of studies included in this review were published after 2011, indicating the relative infancy of this technology and the need for further evaluation of its long-term effectiveness.

Computer- and Internet/Web-based interventions. Identified reviews focused on Internet/Web-based interventions for individuals with type 1 and/or 2 diabetes (31, 96, 105, 124), hypertension (81), somatic diseases (42), asthma (89), or a range of diseases and targeted a large number of self-management behaviors, such as medication adherence, smoking cessation, healthy eating, and increasing physical activity. Interventions most often used computers or the Internet to deliver patient self-management programs and/or some form of contact with a health care professional, or professional advice via email feedback or prompts or moderated/guided forum or self-help (e.g., an online coach). McDermott & While (84) reported interventions incorporating behavior change techniques; those delivered in health-supported settings showed the greatest potential for improving clinical outcomes in patients with chronic illness. Two diabetes-focused reviews (96, 105) reported only those supported by other technologies, such as mobile phones or SMS, and/or health professional support and guidance yielded positive results. Connelly et al. (31) found significant increases in physical activity among individuals with type 2 diabetes, particularly when personal email support accompanied the intervention. Furthermore, Richards & Richardson (108) reported moderate posttreatment effects for computer-based psychological treatments, but interventions supported by a therapist yielded better outcomes and greater retention.

Seven reviews focused on using Web/Internet interventions to promote change in a range of health behaviors, e.g., smoking, alcohol use (78), weight loss (106) and maintenance (131), physical activity (15, 49, 72), or a combination of behaviors (70). Features included automated provision of enriched information (e.g., links, testimonials), monitoring individual progress with tailored feedback, follow-up messages (e.g., reminders, tips), and access to expert advice delivered face-to-face or via email, peer-to-peer discussions boards, forums, or live chat. All studies reported a statistically small but significant effect on those health-related behaviors (129), with the exception of Wieland et al. (131) who reported smaller weight losses and lower levels of weight management compared with in-person interventions. Although only one review completed a meta-analysis, it demonstrated that tailored, Web-based programs were effective for a range of health outcomes, including smoking cessation, physical activity, harmful drinking, and diet (82), thus highlighting that individualized, technology-based interventions produced better outcomes, at least in the short-to-medium term.

Telehealth and/or telemedicine interventions to improve chronic disease management. The interventions evaluated involved remote monitoring and transmission of physiological data, assessment of health symptoms, facilitation of contact with a health care professional via telephone or video, disease-specific education, and reinforcement of self-management behaviors. Six reviews identified the effectiveness of telehealth interventions for chronic obstructive pulmonary disease (COPD) (85, 99), chronic heart failure (65, 100, 104), and diabetes (21), as compared to usual care. One review found over three-quarters of studies (76%) reported positive effects of telemedicine

interventions across a number of chronic conditions (asthma, COPD, heart failure, hypertension, and diabetes) (135). Six reviews reported reduced rates of mortality (65, 85) and hospitalizations (28, 65, 85, 99, 100); reduced BMI and weight (21); increased smoking cessation, medication adherence, and BG self-monitoring (21); and improvements in glycemic control for individuals with type 2 diabetes and across several self-care behaviors, including physical activity and diet (21). Increased quality of life was reported in 66% (seven of nine reviews) of the reviews (28, 65, 85, 99, 100, 125).

Measurement of the usability and acceptance of the technology itself was lacking in most reviews (65), with only one review evaluating patient-nominated barriers and enablers to telehealth use and effectiveness (56). The most commonly identified barriers were technical problems, perceived redundancy, preference for in-person care, technology anxiety, difficulty remembering to interact with the system, need for technical support, and perceived repetition. Identified enablers were improved self-care, increased access to health care, improved health knowledge, ease of use, peace of mind, convenience, effective health management, appreciation of telehealth nurses, and believing telehealth to be as good or better than in-person care. Worthy of note, although older adults, who may not be as technologically familiar as younger groups (51, 67), are the population with the highest burden of chronic disease, no studies cited age as a barrier to intervention success (52, 71). In fact, 53% of American adults aged 65 and older use the Internet or email, and of those who are online, 70% use the Internet on a typical day, and one in six use social networking sites such as Facebook or LinkedIn (137).

Social media and social networking programs. Using social media and social networking to deliver health interventions is still a relatively recent phenomenon. Hence, there are only three reviews of studies utilizing message boards, online chat, chat rooms, and ebuddy systems that match participants with others with similar characteristics. Toma et al. (123) reported reductions in HbA1c, systolic and diastolic blood pressure, triglycerides, and total cholesterol compared to controls. However, the other two reviews (22, 87) that evaluated social media interventions to improve diet, increase physical activity, or both to improve weight management focused mostly on use rather than effects on health outcomes. However, Merolli et al. (87) reported a positive impact of existing and custom-built social networking sites on psychosocial well-being, social interaction, and disease-specific knowledge. Merolli et al. (87) also reported most samples had an overrepresentation of Caucasian, college-educated, employed individuals who were competent Internet users, thus reducing the findings' generalizability. Further research of high methodological quality is required to investigate the potential of social media in this regard.

Although this overview of systematic reviews provides some evidence that technology-delivered interventions can improve the prevention and/or management of chronic diseases and/or lifestyle-related chronic disease risk factors, a number of limitations—summarized in **Table 1** and discussed further in the following sections—must also be considered.

Summary of Limitations

There was considerable diversity in the design and methodological quality of studies, and only five systematic reviews exclusively included randomized controlled trials (RCTs) (5, 8, 15, 28, 31). Small sample sizes, an underrepresentation of samples comprising diverse and disadvantaged populations, and a bias toward health-literate subjects also reduced the generalizability of findings. Several reviews identified effective interventions that were often underpinned by strong theory (94). However, this was not reported in detail by most of the evaluated programs. Of the reviews reporting study location, only eight incorporated studies were conducted outside Western Europe and North America (1, 7, 65, 72, 81, 89, 100, 105), and only two focused specifically on LMICs

Table 1 Key issues relating to the use of technology interventions to improve prevention and control of lifestyle-related chronic conditions

Intervention and program design using new technologies	Lack of heterogeneity of studies
	Bias toward higher income and more literate populations
	Small sample sizes
	Programs and program delivery with poor usability and stickiness
	Lack of theoretical underpinnings to programs and delivery
Evaluation and research issues	Poor evaluation of user perceptions
	Lack of implementation and process measurement
	Inadequate definitions of reach
	Low retention of study participants
	Evaluating new technology interventions with old study and measurement methods
	Inadequate use of large amounts of automated data
Usability, sustainability, and wide uptake of programs	Lack of long-term follow-up
	Inadequate attention to future sustainability and scalability
	Lack of economic evaluation to inform wider implementation and scalability
Context and systems	Rapid pace of technology advancement
	Market saturation in a complex and dense information environment
	Lack of accountability and responsibility for program delivery, funding, and quality control

(37, 98). The heterogeneity of studies included in the majority of systematic reviews precluded formal meta-analysis; 15 (26%) completed formal meta-analyses (28, 42, 44, 80–82, 85, 99, 100, 106, 108, 110, 123, 125, 129). Although some used clinical measures (e.g., reductions in HbA1c for type 1 and/or 2 diabetics), the majority of studies relied on self-reports (e.g., weight, diet). Calls for further research using rigorous study designs, including RCTs, and larger, more representative sample sizes, were common. Finally, few studies undertook economic evaluations, and most encouraged caution when interpreting findings, given a lack of validated measures and long-term follow up. There was relatively little evidence related to program usability and acceptance, making it likely that barriers and enablers to successful implementation, and long-term adverse effects, have been underreported and/or poorly reported. This is most apparent with mHealth programs, where the rapid uptake of smart phones and mHealth apps (61) makes it extremely difficult to properly evaluate the vast majority of these programs.

A New Paradigm Is Required for Evaluating Information and Communication Technology Innovations to Improve Public Health

As occurred during the 1980s and following the first generation of community intervention trials, the very rapid development and application of ICT in public health are seriously challenging our traditional approaches to program design, implementation, and evaluation. For example, the length of time required for study conceptualization, grant funding, conduct of research, and publication of the results of a traditional public health intervention trial means such trials may not be published for six years or more after initiation, particularly if the results are not very positive (63). However, new technologies are currently evolving and changing very rapidly; for example, the

past five years have seen huge advances in technology platforms and applications for mobile health, social media, and wearable smart devices. There is an urgent need to change the prevailing emphasis on and the acceptance of the RCT as the gold standard for evaluating public health interventions using ICT. Although the RCT, with random assignment of individuals, is well suited to the evaluation of highly discrete, well-characterized medical treatments or health interventions, it is limited when applied to complex real-world public health intervention evaluations, where it is often necessary to find an appropriate balance between study design and feasibility or external validity (57, 86, 112). Moreover, the ubiquity of social media and other technology platforms further challenges traditional scientific study designs, which are particularly relevant for the practical application interventions for public health benefit. For example, one study that examined material posted in virtual communities by self-identified clinical trial participants found examples of subjects comparing the physical characteristics of their study drug to determine their assignment to the active drug or placebo (54); and in some forums, participants encouraged one other to withdraw before completion if they could not detect immediate improvement.

The number of studies rigorously evaluating ICT programs with appropriate study designs and high-quality measurement is disproportionately small compared to the number describing their potential benefits. For example, Ye et al. (136) reviewed 122 mental health Internet-based studies on the basis of the quality of the research and found only 25% were rated as strong, and only 6 included all of the quality components included in their rating criteria. The biggest problems were sample selection procedures, particularly the use of convenience samples, which led to self-selected samples, underrepresentation of many populations, problems with randomization and allocation, difficulties in blinding subjects to the nature of the therapy, high drop-out rates, and poor adherence. Others have also noted the high drop-out rates and poor adherence to ICT interventions (27, 126). Although recruitment through social media allows individual study entry, this convenience may also result in a lack of commitment and very low retention rates.

New study designs and approaches to measurement have already been stimulated in recent years by the rapid development of the field of implementation science, and many of these developments are also relevant to the use of ICT for public health programs. These include the increased use of cluster RCTs, stepped wedge design, interrupted time series, multiple baselines, and controlled pre-post designs (112). Adaptive designs have also become particularly popular and are even being used more widely in some clinical trials (2, 79, 91, 101). In adaptive designs, the composition and intensity of interventions can be more individualized and based on the individual characteristics of a user. Subsequently, the program can be adjusted in response to the user's ongoing performance. Adaptive interventions can be operationalized by using decision rules (11) to prescribe the type and intensity or dose of an intervention (79). The advantages and disadvantages of new designs have also been discussed in detail in a series of recent publications (17, 30, 34, 77, 79, 86, 101). Mohr et al. (88) argue that traditional evaluation methods are fundamentally incompatible with Web-based and mobile behavioral intervention technologies, where technological advancements and consumer expectations change quickly, necessitating rapidly evolving interventions. These authors have argued for continued evaluation models in which a newer version of a program is designed in an ongoing trial and subsequently compared with a previous version using an inferiority model (88). This process continues until an optimal outcome is obtained. This approach diverges from traditional models as it is outcome driven—a process that bears similarities to continuous quality improvement but differs in that evaluation of the evidence for improvement is based on ongoing inferiority trials. The evaluation of ICT interventions within large populations where social media is likely to affect outcomes remains a challenge with no simple solutions or models. Interventions may require evaluation as systems or by using approaches based on their reach, cost, and success in achieving outcomes. This also requires use of more trans-disciplinary approaches

and partnerships that involve industry, research, and user groups, while building on traditional approaches that have been previously applied to community-based public health interventions.

RECENT TRENDS IN NEW TECHNOLOGIES AND THEIR APPLICATION TO PUBLIC HEALTH

Lessons from the Commercial and Political Worlds

Although health behavior change programs have been using algorithms to collect information about behaviors for a number of years to provide individuals with tailored, evidence-based advice (116), applications in nonhealth fields are considerably more advanced. The algorithms used by commercial enterprises are often confidential; however, Netflix, Inc., a US provider of on-demand Internet streaming media, has made their approach quite public. With relatively few data points, Netflix uses an algorithm that takes information about an individual, their rating of a movie, how often they watch similar movies, and their viewer history to predict viewing patterns. For online streaming, recommendations are based on what others are watching, the user's costreaming, time of day, and the type of device that might influence ease of download. The algorithm also generates a probability of how an individual is likely to rate it; predictions are matched with ratings, and that information then guides the algorithm to determine its validity. Companies like Netflix have significant capital available to create algorithms, but the same approach can easily be applied to public health and could become a powerful method if combined with data and information from other individuals, for example, via crowdsourcing.

Public health interventions can also use strategies and technology platforms that incorporate live crowdsourced data and that focus on proximal outcomes as small steps toward more significant changes in behaviors as well as longer-term health and clinical outcomes. For example, the methods and strategies used in Barack Obama's team 2008 and 2012 US Presidential campaigns applied this very approach. The goal of Obama's team was to increase the votes for Obama using national-, regional-, and grass roots–level strategies. This involved making voters enthusiastic and ensuring that they would vote in a nonmandatory context. On the macrolevel, Obama's team used social media in a variety of ways, including laddering support through tiers of engagement, empowering super users, providing source materials for user-generated content, using the social networks that were already being accessed by the target audience, using tools people are familiar with, ensuring people could find content, mobilizing supporters through mobile devices, harnessing analytics to improve engagement activities, building the online operation to scale, and choosing the right team. The 2012 reelection campaign may be even more relevant to public health, with its successful use of big data and adaptive designs to determine the most effective ways to raise money. Most of the $690 million Obama raised online came from fundraising emails, and the appeals were the product of rigorous experimentation by a team of analysts who did extensive A-B testing in which, for instance, one email subject line (A) is compared with another (B). This guided the content of the subject lines for requests for donations. The campaign used several strategies determined by data analytics and assisted by social media to achieve their two main goals: (*a*) to influence the undecided to decide and (*b*) to ensure that decided voters did indeed vote.

These examples contain six important lessons for applying contemporary ICT to public health programs: (*a*) clearly define the user population; (*b*) define key relevant proximal and distal outcomes that are important to these users; (*c*) develop multifaceted strategies and approaches to address the proximal and distal outcomes; (*d*) develop a large database that is amenable to small experiments, fine-tuning of algorithms, and further tailoring of strategies to the user population; (*e*) use authoring platforms that allow for rapid and inexpensive updates and adaptations of

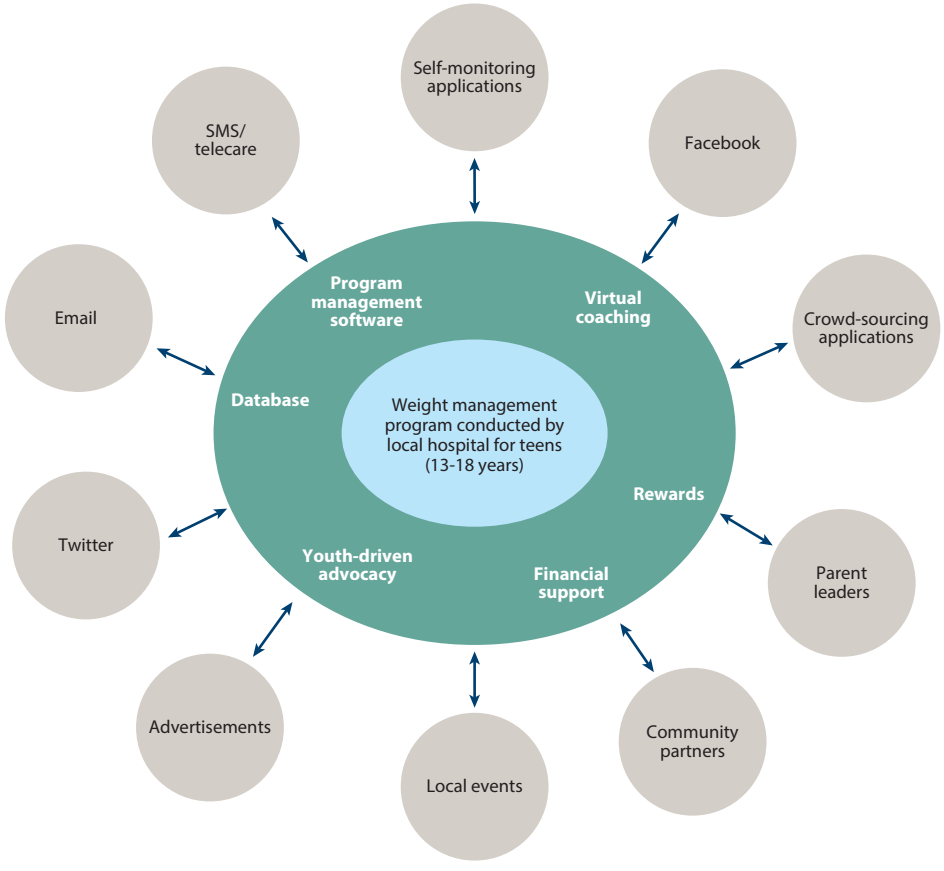

Figure 1

Hub and spoke model as applied to a defined public health problem. The weight-management program was part of the hospital's community/school-based wellness program. SMS, short messaging service.

program content, graphics, and other program features; (*f*) develop multidisciplinary teams with a wide range of expertise that includes program design, epidemiology, statistics, ICT, computer science, health education, and social/behavioral sciences. **Figure 1** summarizes the technologies and other resources and supports that one of the authors (C. Barr Taylor) has been using with young students to help them achieve weight maintenance and/or weight loss by variously using program management software, virtual coaching, rewards, financial support, youth advocacy, and a large database for program improvement in real time and evaluation. The following two case examples being researched by authors of this manuscript—C. Barr Taylor and B. Oldenburg, respectively—illustrate application of the six lessons discussed above.

Case Example 1: The Student Bodies-Eating Disorders Program

The Student Bodies-Eating Disorders (EDs) program illustrates how online interventions are being developed to expand reach to different segments of a population using experiences from the first year of intervention by further adapting and developing the program and its delivery (18, 122). The overall goal of a healthy body image is to reduce the incidence and prevalence

of eating disorders, to improve the treatment of individuals with EDs, and to affect the culture around issues of body image/weight in a positive direction. The Student Bodies-EDs program involves recruitment with randomization at the college/university level. Students are recruited through various social media outlets, listservs, and school-based advertisements and activities; they complete a screen and are then assigned to different online conditions (48, 132). Preliminary analysis has found that the recruitment rate for eligible students was higher than in previous studies using traditional recruitment methods, including a pilot (66) (~70% and ~44%, respectively). Given the ease with which potential users (students) can enter the program, it is plausible that many are entering out of curiosity rather than as committed participants, which leads to many participants who completed the baseline screen and assessment being deemed ineligible for the main trial (122). However, as the participants were recruited at the population level, it became possible to look at other segments of the student body that are not part of the trial but might benefit from intervention. Following screening, the component programs are being expanded to address populations that are overweight but have no eating disorder or risk for eating disorder, and programs are being developed for male populations and for subpopulations, including lesbian, bisexual, gay, and transgender populations that may require tailored interventions and programs or those that focus more on the prevention of relapse than intervention. In addition, depending on the sample size, it is possible to undertake other studies within the framework of the main study to determine the effects of the intervention within these subgroups or to author new components of the intervention to address these subgroups, which could then be randomized to controlled studies. In short, although some registrants were not eligible for the main trial, they can be offered a prevention program more tailored to their needs through the same platform used in the study (128). These kinds of online programs can then be developed, evaluated, and offered as part of a suite of prevention and intervention programs to a defined population.

Case Example 2: A Digital Program for Self-Management of Diabetes Using Interactive Voice Recognition and Automated Conversation

Self-management of type 2 diabetes requires adoption and maintenance of several key lifestyle and self-care behaviors (e.g., dietary change, self-monitoring of BG, medication adherence, foot and eye care). By so doing, people with diabetes can reduce their risks of complications, thus improving their quality of life and reducing health care costs. Because of the rapid increase in rates of diabetes in all countries around the world, including LMICs, traditional approaches to diabetes education and self-management that require face-to-face delivery by health professionals can no longer provide programs to such large populations. Furthermore, self-management of lifestyle-related chronic conditions, such as diabetes, requires ongoing education, monitoring, and coaching over the increasing number of years people live with diabetes. The Australian Telephone-Linked Care (TLC) Diabetes Project, using a technology that was originally developed in the United States to help people better self-manage various lifestyle behaviors and conditions, was developed as an automated conversational platform to provide education, monitoring, and coaching for people with diabetes to improve their self-care and improve their diabetes control (12). The original TLC Diabetes platform consisted of a PC connected to the phone network, equipped with high-quality speech recognition, over 2,000 prerecorded conversation statements, and a database that stored each caller's responses to enable tailored feedback and information during each telephone call. Users uploaded BG readings to the TLC database via a cell phone link prior to engaging in weekly, scripted automated conversations related to BG monitoring, nutrition, physical activity, and use of medication. The conversation scripts featured feedback from BG results and physical activity goals, sent alerts, and initiated human intervention when clinical and other alerts were generated.

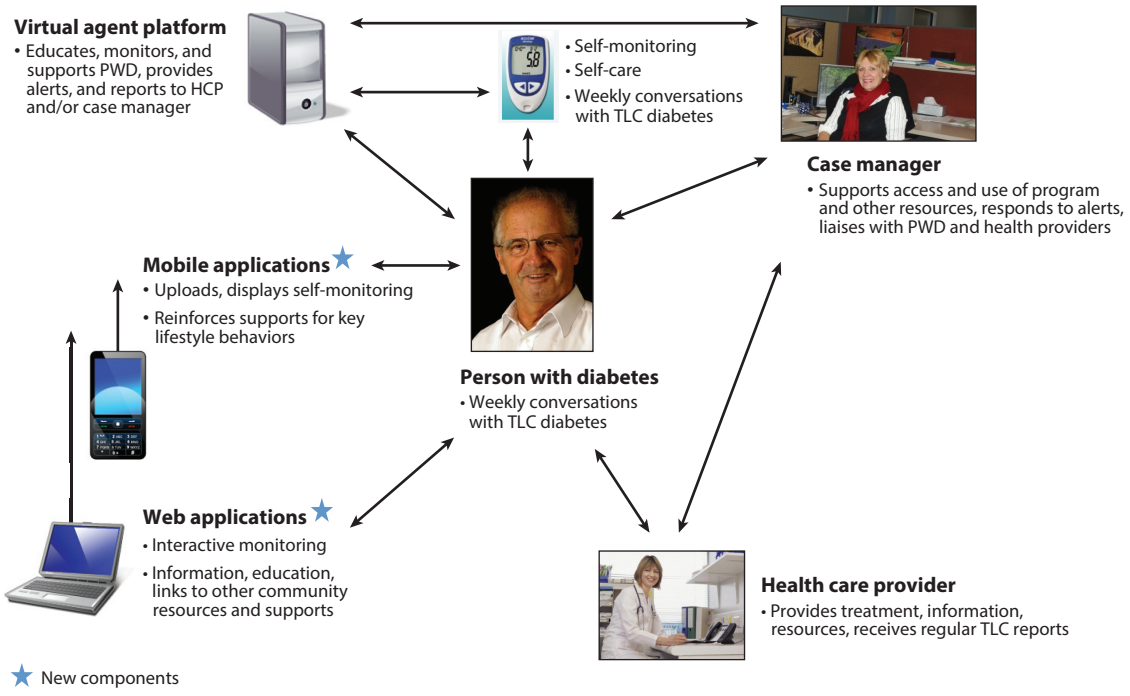

Figure 2

Telephone-Linked Care (TLC) Diabetes platform, a program using technology to improve self-management of diabetes. Abbreviations: HCP, health care provider; PWD, person with diabetes.

In a randomized study of people with suboptimally controlled type 2 diabetes, the program significantly improved glycemic control and mental health function (12, 133). An economic evaluation also demonstrated that TLC Diabetes was a low-cost delivery platform and that study participants receiving the intervention had lower medication costs (55). The implementation, adoption, and usability of the program were exceptionally strong with participants completing more than 75% of expected calls, which was equivalent to almost 200 minutes of tailored support provided to each person over six months. Building on recent advances in mHealth and related technology, an improved digital diabetes program is now tailoring its delivery to each user's needs and generates automated reports for health care providers (illustrated in **Figure 2**). More specifically, it is using virtual agent technology with enhanced artificial intelligence capabilities, which can now be accessed online.

FUTURE CHALLENGES AND ISSUES

Defining the Target Population and Responsibilities for Quality Program Delivery

Within the old communications landscape, populations were defined by their geography or by their location within particular settings in the community; however, it is now possible to conceptualize and reach populations in a much more virtual way, as described in the previous sections. Indeed, connecting with individual users of defined populations from an online community means that

membership can be determined by the mere click of a button, and engagement can be both dynamic and transient. However, we have traditionally based the delivery of health care services and public health programs on geographic catchment areas, and the first generation of community intervention trials in the 1970s and 1980s was heavily influenced by that way of conceptualizing a population and community. However, if we conceptualize the delivery of public health programs in a much more virtual way, several key questions and issues arise. With whom does accountability lie regarding program regulation, evaluation, quality control of its delivery, and its use? What is the role of traditional service providers, not only in facilitating the appropriate uptake and use of the program, but also in embracing or adopting new technologies? Most importantly, the user experience is critically important, and programs need to be easy for individuals, communities, and organizations to adopt, implement, and refine (9).

Market Saturation

A complex and increasingly dense information environment has been created by the sheer volume of health-related information available on the Internet, and the number of health-related applications and technologies can result in what has been called data smog. Google's Our Mobile Planet survey, which tracks smart phone usage across 48 countries, reported that the average smart phone user downloads 25 apps (50) and launches apps 10 times per day (4). By June 2013, 43,000+ mHealth care applications had been developed worldwide, including 16,275 that were considered patient oriented and 1,980 that targeted specific therapy areas. In this crowded marketplace, it has become difficult to attract and to keep long-term users (27, 45, 69), making the lessons learned from the political and commercial spheres about continually improving program usability and stickiness to maintain patient engagement even more important.

Digital Technology as a Disruptive Innovation for Delivery of Public Health Programs

As the diffusion of innovations theory suggests, some subgroups in the population will reject or resist technology-based health interventions; however, this group is becoming smaller over time (95). A complex range of factors can negatively influence the uptake and/or integration of new technology innovations by potential health care users (26), such as health professionals' concern about their own professional practice becoming obsolete. However, there is little doubt that the application of ICT to public health innovations is already beginning to disrupt traditional health care delivery systems and approaches that have been used to prevent and manage chronic conditions, including CVD and diabetes, over the past 40 years.

Theory to Inform Delivery of More Effective Information and Communication Technology–Based Public Health Interventions

Although mobile technologies are rapidly evolving as a platform for delivering health behavior interventions that can be tailored to the individual throughout the process, the content and timing of these procedures have not been well underpinned by appropriate health behavior theories (109). This highlights the need to develop health behavior theories and models that can (*a*) capture and predict how to adjust intervention messages and feedback in response to user feedback in real time to optimize behavior change and maintenance; (*b*) account for complex, time-varying patterns of user input about behavioral and contextual factors and intervention component options as they

influence targeted behaviors; (*c*) acknowledge that the interpersonal dynamics involved in social network behaviors are opportunities to share, shape, and respond publicly to eHealth messages and can influence the impact they have on decisions, behaviors, and health outcomes; and (*d*) consider models of rewards that nudge, reinforce, and shape behavior change in the long term (107).

Information and Communication Technology to Transform the Delivery of Public Health Programs in Low- and Middle-Income Countries

With the rapid adoption of mobile devices throughout the world, mHealth and technology-based public health interventions have the potential to reshape the delivery of health care, particularly in traditionally underserviced LMICs (98). Although the current evidence base for the use of mHealth and ICT-based interventions in LMICs is still limited, it is set to expand rapidly in coming years as demonstrated by the joint mHealth initiative between the International Telecommunication Union and the World Health Organization. This initiative is focused on the use of mobile technology, in particular text messaging and apps, to combat noncommunicable diseases (**http://www.itu.int/net/pressoffice/press_releases/2012/77.aspx#.VDttwfmSx8F**). Indeed, the penetration of ICT in developing countries, where wireless technologies have leapfrogged traditional computer infrastructure, has created new and exciting opportunities and possibilities to reach populations who were largely unreachable via traditional communication channels (109).

CONCLUSIONS

Strong theory-based interventions that targeted health behavior change in high-income countries using the available media and communications of the day contributed to the reduction of disease risk of populations within the old communications landscape of the 1970s and 1980s. However, the real benefits of population-based programs using ICT within the new communications landscape for improving the prevention and management of chronic diseases, such as heart disease and diabetes, still require further and more detailed evaluation. Traditional approaches to study design and measurement are now largely inadequate for addressing questions related to efficacy, effectiveness, and related issues where ICT is concerned. We recommend the application of new approaches to the design, implementation, and evaluation of ICT interventions, influenced by the commercial and political worlds, and the use of more dynamic approaches to address their continuous quality improvement.

DISCLOSURE STATEMENT

The authors are not aware of any affiliations, memberships, funding, or financial holdings that might be perceived as affecting the objectivity of this review.

ACKNOWLEDGMENTS

Mr. Tilahun Nigatu is thanked for his assistance with identifying and coding the systematic reviews summarized in this article. Dr. Fabrizio D'Esposito and Ms. Nitya Kunari are thanked for their assistance with editing and refining the manuscript. Dr. Adrienne O'Neil is a recipient of a National Health and Medical Research Council (NHMRC) Early Career Fellowship (1052865). Dr. Fiona Cocker and Professor Brian Oldenburg receive support from a NHMRC Partnership Project grant (1057411).

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